A Physics-Informed Neural Network for Electric Field Modeling in Microstimulation

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Objective

To develop a physics-informed neural network (PINN) that predicts continuous electric-potential and electric-field distributions for microelectrode stimulation.

Background

Neural responses to microstimulation are governed by the spatial structure of the electric field rather than current alone, with multielectrode configurations producing complex field patterns.

Existing modeling approaches force a tradeoff between computational efficiency and physical fidelity.

PINNs address this gap by embedding the governing equations of electric potential directly into the learning process, enabling continuous, differentiable field representations.

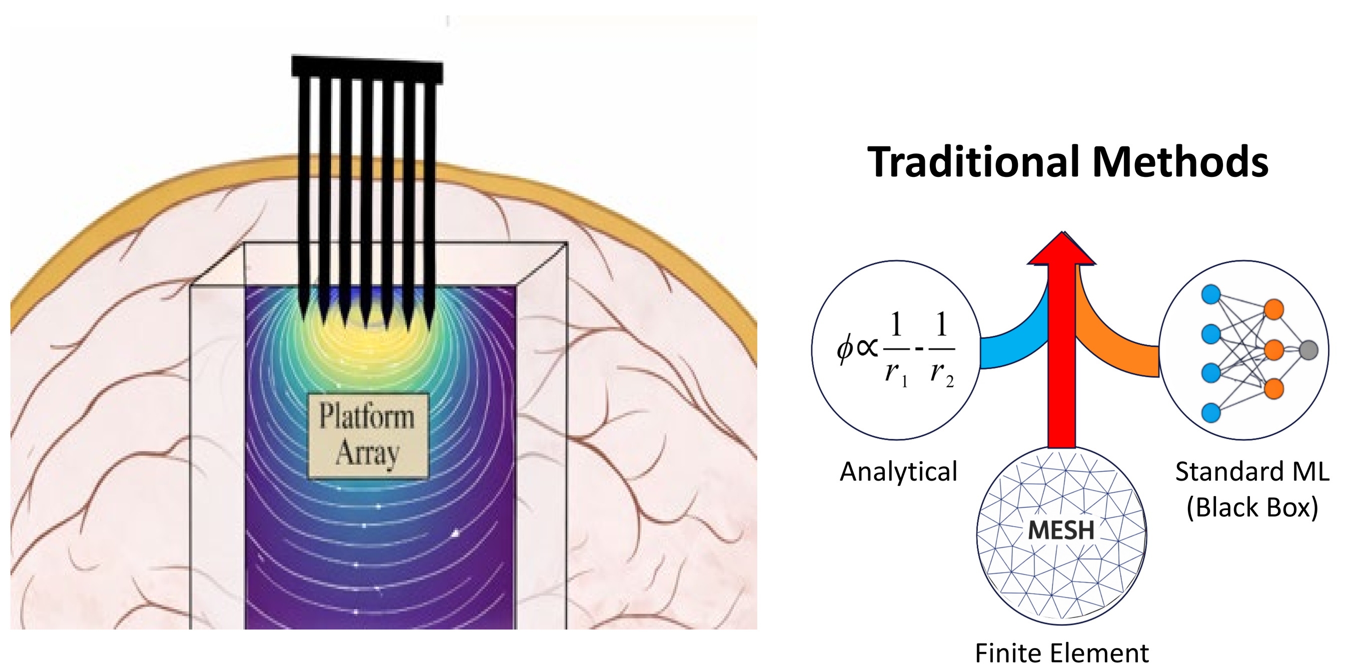

Figure 1. Conceptual overview of field modeling.

Methods

The PINN is trained to solve the quasi-static Laplace equation, with the loss function enforcing the governing PDE and boundary conditions. The network takes spatial coordinates and electrode position parameters as input for rapid field prediction under varying configurations.

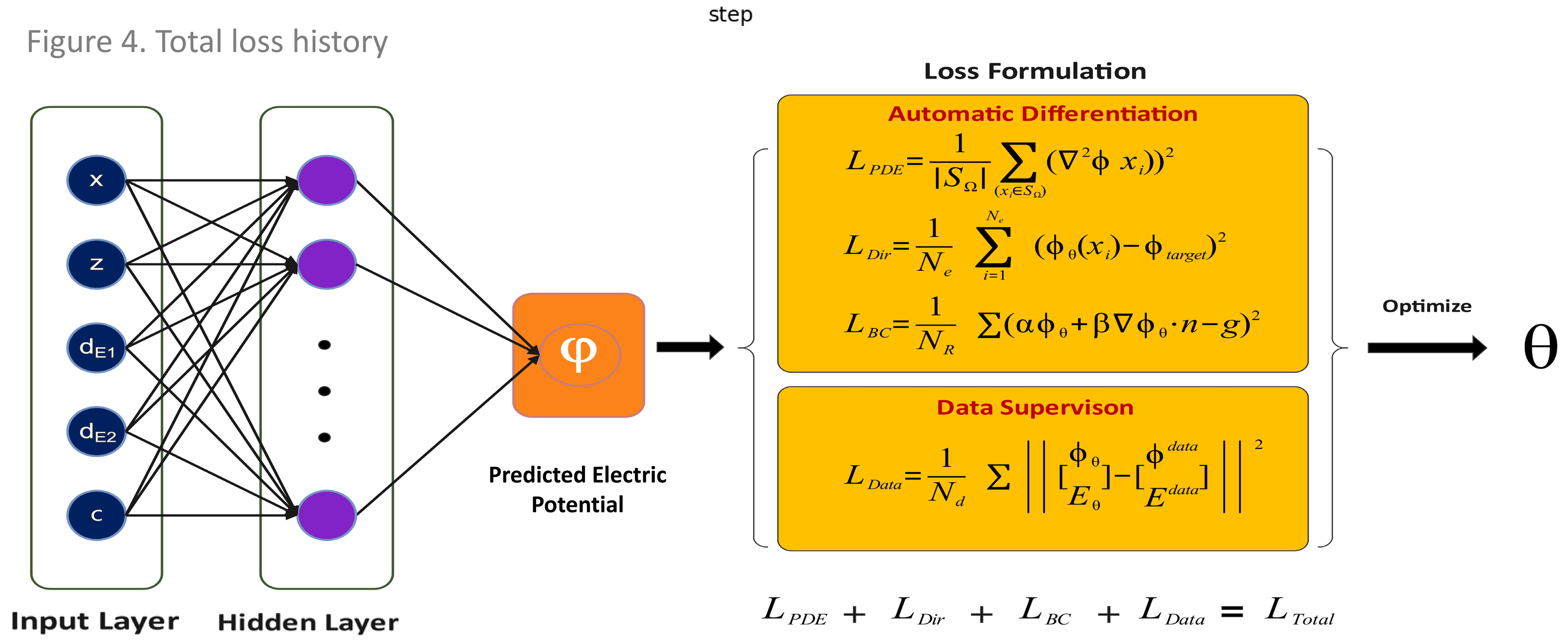

Figure 2. PINN training workflow. The network predicts the electric potential; spatial derivatives are computed via automatic differentiation to enforce the governing physics. Supervised data is incorporated, and all terms are combined into a total loss used to optimize the network parameters θ.

Results

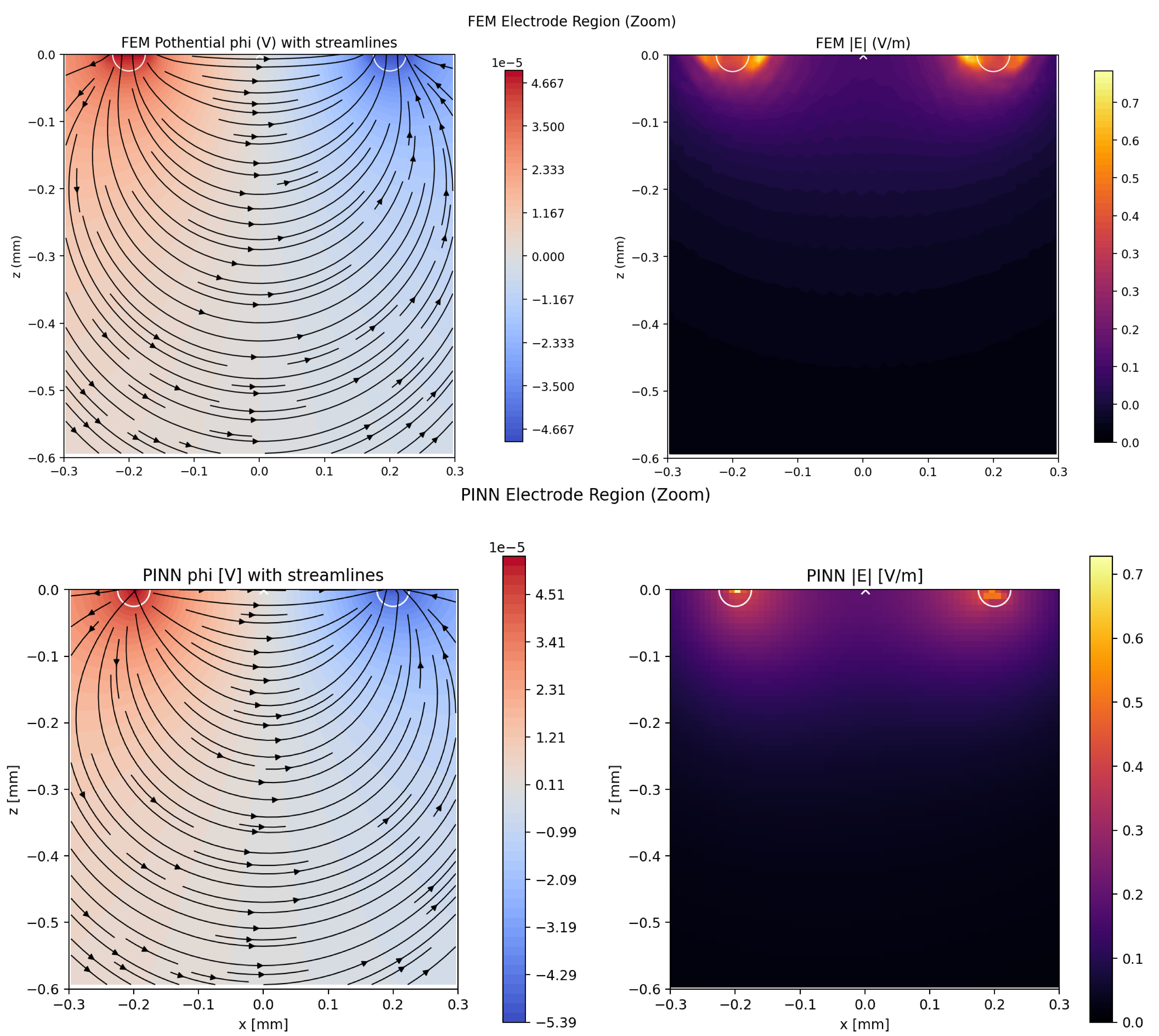

Figure 3. FEM and PINN Comparison

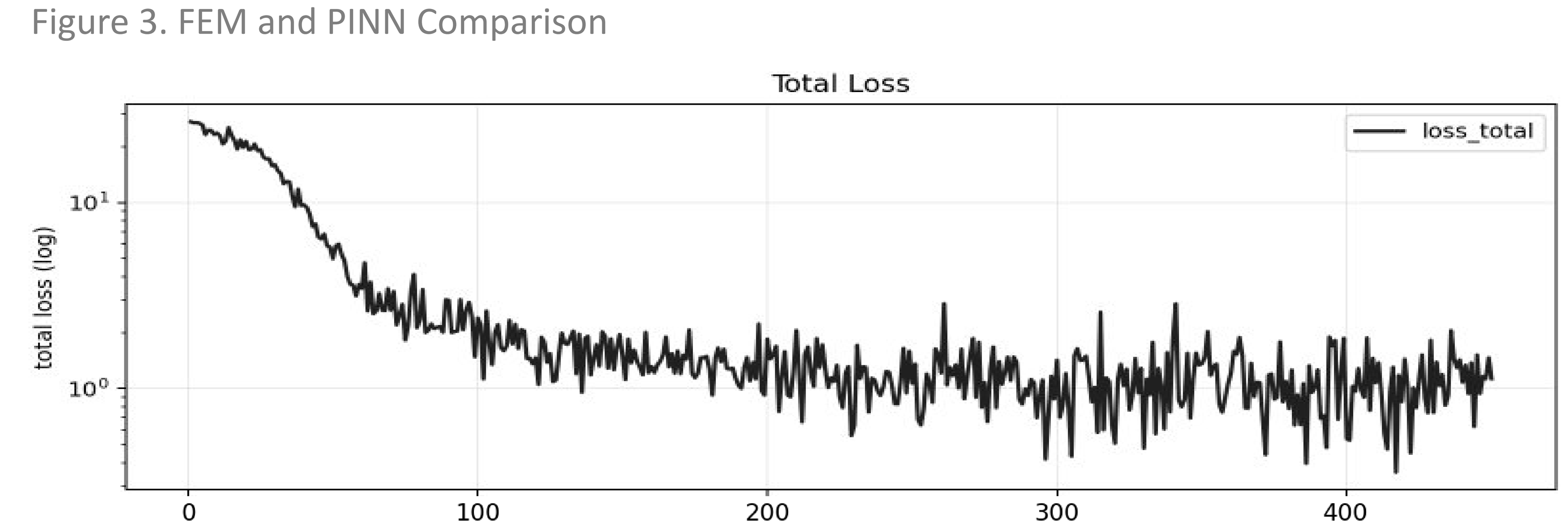

Figure 4. Total loss history

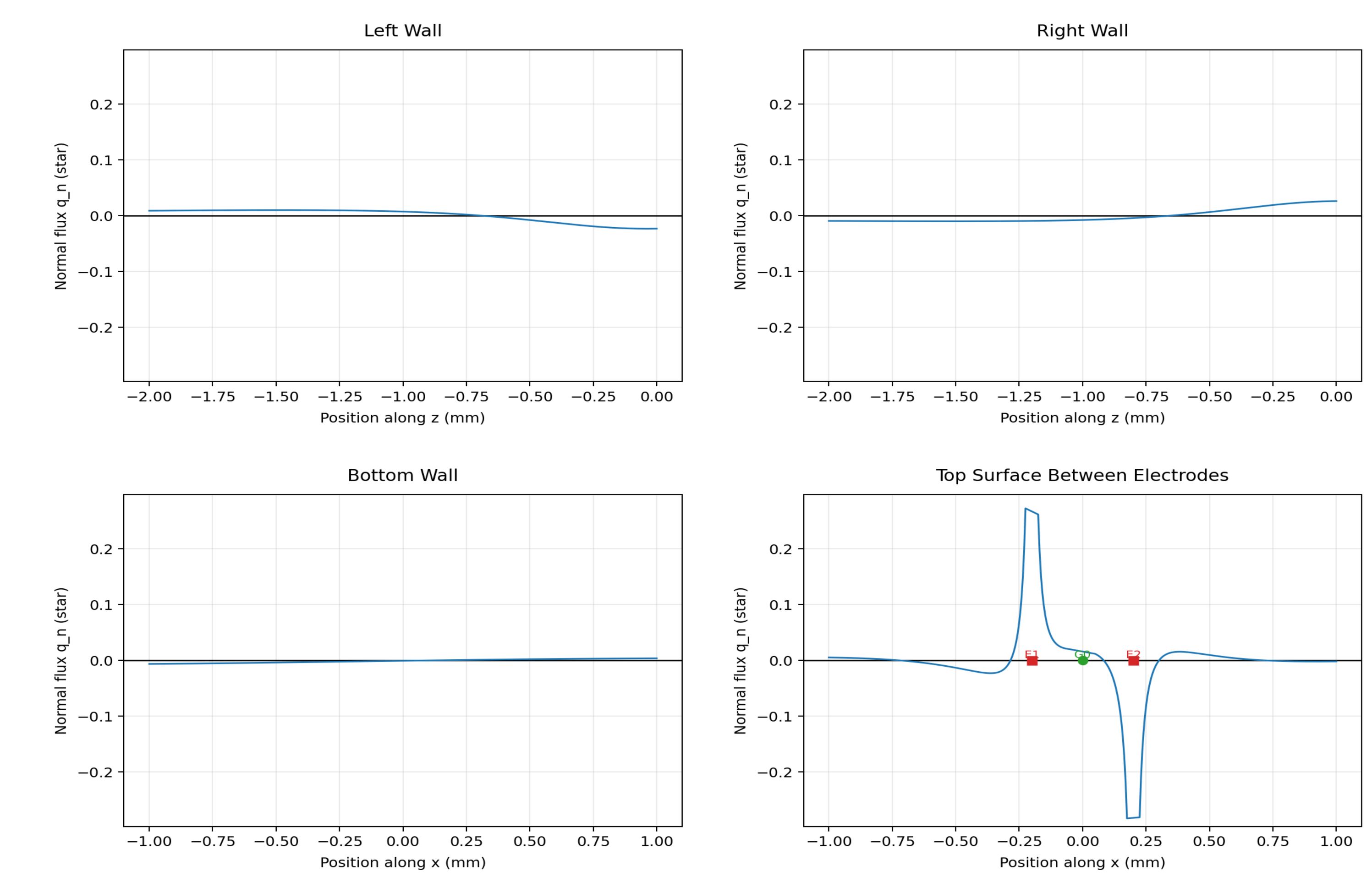

Figure 5. PINN Flux closure

Metric	PINN	FEM	Speedup
Compute Time	.02s	.24s	12x

Key Result

The PINN model enables near–real-time field evaluation (~12× faster than FEM) while preserving physically consistent solutions.

Conclusion

The 2D PINN prototype shows agreement with FEM solutions while significantly reducing computational cost. These results suggest the approach is a promising surrogate model, with future work extending to 3D geometries and more complex stimulation configurations. This work establishes a foundation for physics-consistent field modeling compatible with rapid simulation pipelines.

Acknowledgements

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